Canada Alberta

FOREST RESOURCE DEVELOPMENT AGREEMENT
ENTENTE SUR LA MISE EN VALEUR DES RESSOURCES FORESTIERES

Canada Alberta

The Canada–Alberta Forest Resource Development Agreement is a subsidiary agreement of the Canada–Alberta Economic and Regional Development Agreement, which provides coordination and cooperation between the governments of Alberta and Canada in areas of Alberta's economic development.

The Canada–Alberta Forest Resource Development Agreement is funded equally by the governments of Canada and Alberta, from April 1, 1984, to March 31, 1989.

Its primary objectives are to ensure the long-term availability of timber supplies; to optimize timber uses; and to contribute to the growth and diversification of Alberta's economy.

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Ses objectifs principaux sont assurer la disponibilité à long terme de réserves de bois; optimiser leur utilisation; et contribuer à la croissance et la diversification de l'économie de la province.

L'Entente comprend trois programmes: Reboisement; Recherche appliquée, transferts de connaissances techniques et relevé des occasions; et Information, évaluation et administration. Ces programmes sont gérés par un Bureau de direction conjoint, et mis en oeuvre par Forêts Canada et le Service forestier de l'Alberta.

For more information, please call or write:

Pour de plus amples informations, veuillez vous adresser à:

Forestry Canada
Northern Forestry Centre
5320 - 122 Street
Edmonton, Alberta
T6H 3S5
Telephone: (403) 435-7210

OR/OU Alberta Department of
Forestry, Lands & Wildlife
9915 - 108 Street
Edmonton, Alberta
T5K 2C9
Telephone: (403) 427-3583

REFINEMENT AND MILL TRIAL OF A NEW MOISTURE TOLERANT PLYWOOD ADHESIVE SYSTEM

Forintek Canada Corp.[1]

1988

P.R. Steiner, M.R. Clarke and A.W. Andersen

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[1]6620 N.W. Marine Drive,
Vancouver, B.C.,
V6T 1X2

Project # 18201-75

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Forestry Canada
Regional Development
5320 - 122nd Street
Edmonton, Alberta
T6H 3S5
Telephone: (403) 435-7210

or

Forestry, Lands and Wildlife
Forest Industry Development Division
108th Street Building
#930, 9942 - 108th Street
Edmonton, Alberta
T5K 2J5
Telephone: (403) 422-7011

ABSTRACT

The viability of plywood manufacturing plants is dependant upon continual improvements in process efficiency. Drying and pressing operations are two facets where technological improvements can have a significant effect. Phenol formaldehyde adhesive which can accommodate hot pressing of higher moisture content veneers offers benefits by reducing drying costs while improving panel dimensional stability.

A unique phenol formaldehyde dispersion glue, having broad applications to wood bonding, has been developed at Forintek. The system consists of two phases. One component is an advanced PF polymer, initially formed as a powder dispersion, which is insoluble but swellable when mixed in a second component consisting of an alkaline, plywood adhesive. A family of moisture tolerant dispersion glues can be produced by adjusting advancement level of the higher molecular weight component and mixing the two components in various proportions. The resulting mix can be applied without fillers.

These glues are effective in bonding veneers of 12 ± 2% average moisture content under laboratory conditions. A number of small trials demonstrated the compatibility of these formulations with commercial spray systems. These glues provided excellent prepress properties at all tested veneer moisture contents. The viability of these dispersion glues was further demonstrated at a mill trial at Zeidler Plywood in Edmonton where over 300 panels were manufactured.

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1.0 INTRODUCTION

The reputation of phenol formaldehyde (PF) resins as strong, durable and reliable wood adhesives has led to their use in plywood manufacture. The demands for increased panel production volumes and cost efficiency however, has revealed some curing and application limitations in certain PF formulations.

Bonding veneer at increased moisture levels offers significant advantages for plywood manufacturing efficiency and panel quality. These include: reduced costs in terms of both drying times and drying energy, improved veneer flexibility leading to less downgrade from veneer breakage, extended assembly times, improved heat transfer in the press and enhanced dimensional stability since the moisture content (m c) of the panel leaving the press can now approach the moisture level it will experience in service. Many of the present PF formulations, however, are unsuitable for bonding higher m c veneer because of poor cure times and adhesive overpenetration problems. The chemistry of phenolic resins is made complex by the multitude of possible reactions and the limited solubility of high molecular weight components. By altering the physical form of PF resins, through pH adjustment and resin advancement, distinct systems can be produced which give improved resin properties for bonding higher m c wood. Filler free plywood glue mixes may be feasible with proper combinations of PF component molecular weight and size.

Capabilities for bonding higher m c veneers are further enhanced by sorting veneers according to moisture level and incising these veneers to increase vapour permeability. These incisions offer a means for moisture to redistribute during panel pressing leading to reduced blister formation when the press opens. Consequently the favoured strategy for bonding higher m c plywood panels involves a marriage of veneer moisture sorting, veneer incising and adhesive technology.

Preliminary experiments have established that filler free adhesives for bonding higher m c veneers can be formed with mixtures of insoluble phenolic dispersions with soluble phenolic resin. The objectives of this project was to use this technology to:

- formulate a PF system combining high and low molecular weight components which is suitable for bonding veneer between 8 and 10 % m c.
- develop procedures for preparing and applying large scale quantities of these adhesives.
- conduct a limited number of mill trials with these formulations.

2.0 STAFF TEAM (COMPOSITES DEPARTMENT)

P.R. STEINER	Research Scientist
M.R. CLARKE	Manager
A.W. ANDERSEN	Research Scientist
D. WALSER	Research Scientist
K. CHAN	Technologist
C. LAI	Technologist
B. MARK	Technologist
P. TARASOFF	Technologist
N. WALSER	Technologist
C. NORMAN	Summer Student

3.0 EXPERIMENTAL

3.1 MATERIALS

PF adhesives used in this study were modifications of commercial plywood resins designated as either resin A (Borden PF 658) or resin B (Reichhold IB 334). In addition Borden's 2020 moisture tolerant glue also was used in comparison trials.

Veneer for laboratory and mill trials was either white spruce, lodgepole or ponderosa pine or balsam fir species commercially peeled to 1/8 in. (3.2 mm) thickness. These materials were incised in a 48 in. (120 cm) wide , laboratory machine using a reverse bend incising pattern to give incisions 0.8 in. (2 cm) long and 0.8 in. (2 cm) apart along the grain direction. Small veneer sheets for laboratory bond tests were placed in conditioning chambers to achieve 10 ± 2% average m c. Larger veneer sheets 48 in. x 30 in. (120 by 80 cm) were stacked between spacers and air dried at room conditions (68°F (20°C) /50% R H) or kiln dried at 120 to 130°F (50 to 60°C) at 65% R H.

3.2 RESIN FORMULATION DEVELOPMENT

Resin precipitation was undertaken in volumes ranging from 2 to 40 gal. (8 to 160 liters). In a typical precipitation, a mixture containing equal quantities of plywood resin and water were stirred with a 8 in. (20 cm) diameter high shear disc rotating at 800 RPM. Sulfuric acid solution (10 % concentration) was slowly added to the mixture over a period of 40 minutes. As pH decreased, mixture viscosity increased until most of the resin had precipitated, whereupon the mixture viscosity significantly decreased. The resulting dispersion was adjusted to pH 5.5 and washed several times with equal volumes of water. Final PF solids content was adjusted to 35 %. A heat exchanger with hot water circulating through it was used to heat the dispersion and advance the polymer. In some cases dispersion pH was adjusted to between 2 and 5 prior to heating.

To characterize dispersion advancement, samples were removed at various heating times and filtered to yield a PF powder. This powder was added to a NaOH solution in different amounts to give mixtures containing a constant ratio of 27 % NaOH to the weight of PF polymer (same as original plywood resin) but with varying PF solids contents. Each of these mixtures was held at room conditions for 2 hr to allow for full swelling of the PF powder. Viscosity determinations were made on a Brookfield LVF viscometer using spindle 4 at 30 or 12 RPM. Viscosity-solids curves were constructed from the values.

Glue-formulation-working properties were determined by systematically mixing dispersion components ranging from 45 to 25 % amounts with plywood resin components ranging from 55 to 75 % based on PF solids weight. The PF solids contents of these mixtures were adjusted to between 30 and 35 %. Mixtures were allowed to stand at room conditions for 2 hr before viscosities were determined.

3.3 CURE STUDIES

Bonding studies were undertaken using incised spruce veneer strips 4 in. by 15 in. (100 by 380 mm) at 12 ± 2% m c. Four ply panels were assembled with parallel grain orientation. Using matched veneers, a group of three panels was pressed at a time. One panel of each set was bonded with a commercial, moisture tolerant glue mix (Bordens 2020) to provide a control panel. Glueline spread levels were 0.013 lb. (6.1 g) for the commercial mix and 0.009 lb. (4.1 g) for the dispersion mix to give spreads of similar PF levels. After 15 min closed assembly time, panels were pressed at 175 psi (1.1 MPa) for times ranging from 3.0 to 6.0 min at press temperatures of 300°F (150°C). Plywood shear type specimens were cut from these panels and tested after standard vacuum pressure soak treatment (CSA 0151, 1978).

3.4 LABORATORY SPRAY SYSTEM

A spray system was constructed in our laboratory to help determine application options for dispersion resins. The apparatus consisted of a 16 foot (5 meter) long, variable speed conveyor line, an adjustable height spray nozzle, a large capacity recirculating pump capable of generating 300 psi (2.1 MPa) pressure and high pressure hosing connecting the pump to the spray nozzle. All this equipment was enclosed in a wood frame which was covered in plastic to retain glue overspray. The system was used to assess application characteristics of different viscosity glue formulations in relation to spray nozzle size, line speed, spread level, glue temperature and pump pressure.

3.5. SMALL MILL TRIALS

Three small mill trials were undertaken at Cantree Plywood in New

Westminster. Batch quantities of dispersion resin, 330 to 440 lbs (150 to 200 kg), were prepared in our laboratory. Commercial white spruce and lodgepole pine veneer in green condition was shipped to the laboratory where incising and drying (either by air drying or kiln drying methods) to 10 to 16 % mc took place. Both glue and veneer were transported to the mill a day before the trial.

The first trial tested the mill spray system using a glue mixture of 35 % PF dispersion with 65 % plywood resin at 35% total PF solids. Glue viscosity was about 9000 cps.

The second trial used a mix containing 33% PF dispersion in 67 % plywood resin at 33 % total PF solids to give a viscosity of about 4000 cps. The mixture was passed through a 40 mesh screen to remove large particles. This trial used only one spray booth and manual panel layup. Assembly times range from 10 to 40 min. Ten, full size five-ply spruce panels were produced with the dispersion resin formulation being applied at 54 lbs (24.5 kg) MDGL. A similar set of panels were prepared with a moisture tolerant plywood glue formulation (Bordens 2020) applied at 65 lbs (29.4 kg) MDGL on to incised veneer. The veneer was determined to be about 12% average m c as measured by a ring type moisture meter (subsequent oven dry tests showed the veneer to actually be about 18% average m c). Both panel sets were prepressed 4 min at 145 psi (1 MPa) and then hot pressed at 190 psi (1.3 MPa) pressure and 280°F (138°C) for 5 min. Panels were scanned through an ultrasonic blister detector. Oven dry m.c. was determined for strips cut from several panels just out of the press.

The third trial used incised veneer (75 % spruce and 25 % pine mixture) kiln dried to about 9% average m c (oven dry value). Approximately 550 lb. (250 kg) of dispersion glue mix was prepared containing 34% dispersion component and having 34.5 % PF solids to give an initial viscosity of 9500 cps. Viscosity was adjusted to 2800 cps by addition of about 2.2 lbs (1 kg) of 25 % NaOH solution.

Panels were manufactured in a similar manner as in trial 2 except that two spray booths were utilized to allow faster assembly. Fifteen panels were pressed for each glue, press temperature was 300°F (150°C) and press time was 5.5 min. Panels were hot stacked overnight prior to trimming and scanning through a blister detector.

3.6 LARGE MILL TRIAL (ZEIDLER PLYWOOD, EDMONTON)

Nine hundred and ninety lbs (450 kg) of PF resin were precipitated and washed in the usual manner. This dispersion was advanced by heating to 35°C for several days. Advancement was monitored continually by preparing 1 lb (454 gm) glue mixes, testing their viscosity and assessing bond quality of small panels made with these adhesives. The dispersion was shipped to Edmonton several days before the trial.

Eight lifts of green veneer (about 1500 sheets) were obtained from Zeidler mills. These consisted of regular mill material and contained about 50%

pine with the rest being spruce and balsam. About 20 % of this veneer contained rot. The veneers were incised and divided into several lots before being placed in a dry kiln. A mild kiln schedule of 150°F (65°C) and 65% R H was used to bring the veneer to about an 8 % average m c over a 48 hr period. Following drying, veneer bundles were wrapped in plastic and shipped to Edmonton.

The glue mix was prepared a day before the mill trial using a 500 gallon (1890 liters) mix tank at Borden's Edmonton facility. The dispersion had settled to the bottom of the barrel during shipping and some difficulty was encountered in redispersing this material. Thirteen hundred lbs (600 kg) of plywood resin initially were put into the mixing tank and then 990 lbs (450 kg) of dispersion added while stirring the mixture. Overall shear action of the mixer was poorer than previous test runs. Following dispersion addition a further 550 lbs. (250 kg) of plywood resin was added to the tank and the total mixture stirred and allowed to swell over a period of four hours. This mixture consisted of 35% PF solids and contained 33% dispersion component. Final mixture viscosity was adjusted to 1850 cps by addition of 55 lbs (25 kg) of 25% caustic solution.

In the mill, a standard GP line was used to assemble five-ply, 5/8 in (15.9 mm) standard plywood panels. Quantities of incised veneer, kiln dried to about 8% average m c were placed at each layup station. The dispersion glue mix was transferred into the regular mill glue storage tanks and circulated to all the spray booths. Four spray booths were employed during layup. To allow for spray level adjustments, Zeidler standard mill veneer was used to layup the first press load. A total of 15 press loads (30 openings per press load), were manufactured and sampled. A summary of veneer and glue combinations and pressing conditions used is given in Tables 1 and 2. Panels were hot stacked overnight before five test panels were removed from each load.

3.7 PANEL ASSESSMENT

A total of 75 panels were taken for assessment. Panels initially were scanned through a blister detector (Trienco, 6 sonic head model) set to detect 3 in (7.5 cm) and greater delaminations. Panels were also visually inspected for delamination.

Strips were cut out of the middle of at least 5 panels randomly selected from each set of veneer and glue combinations. Plywood shear specimens were cut from these strips and 10 specimens each per panel were treated to vacuum pressure soak and boil dry boil cycles as described in CSA 0151. Specimens were broken and shear strength and wood failure tabulated.

TABLE 1.

SUMMARY OF PRESS LOAD COMBINATIONS DURING ZEIDLER TRIAL

LOAD NO.	VENEER TYPE	GLUE TYPE
1	Standard mill	Forintek dispersion
2	Incised, high m.c. full sheets with standard mill crossbands	Forintek dispersion
3 to 8	Incised, high m.c.	Forintek dispersion
9	Incised, high m.c.	Borden 2020
10	Incised, high m.c.	Borden 2020
11	Standard mill	Borden 2020
12	Standard mill	Borden 2020
13	Standard mill	Forintek dispersion
14	Standard mill	Forintek dispersion
15	Standard mill	Forintek dispersion

TABLE 2.

BONDING CONDITIONS FOR ZEIDLER TRIAL

Glue spread level[+]:	60 to 65 lbs (27 to 30 kg) MDGL; 52 to 56 lbs (23 to 25 kg) MDGL
Glue application temp:	83°F (28°C)
Prepress pressure:	130 psi (0.82 MPa)
Prepress time:	3.5 min.
Press temp.[*]:	300°F (150°C); 285°F (140°C)
Press time:	5.5 min.
Press pressure:	200 psi (1.26 MPa) for first 5 min. then 140 psi (0.88 MPa) for last 0.5 min.

[+] Borden's 2020 mix spread at 60 to 65 lbs (27 to 30 kg) MDGL
Forintek dispersion resin mix spread at 52 to 56 lbs (23 to 25 kg) MDGL

[*] First three loads pressed at 300°F (150°C); remaining loads pressed at 285°F (140°C)

4.0 RESULTS AND DISCUSSION

4.1 RESIN FORMULATION DEVELOPMENT

The principle used in developing a suitable moisture tolerant PF formulation was to first form a high molecular weight PF component. This component then was mixed with a standard PF resin in proportions determined to give a system with desired application and bonding properties.

The higher molecular weight components were formed by initially precipitating either of two plywood phenolic resins. Both resin systems followed similar patterns during acid precipitation with the PF polymer remaining soluble down to about pH=11, whereupon thickening of the solution occurred. Between pH 10 and 11, a two phased mixture formed which consisted of solid particles distributed in a thick syrup of PF polymer. Further neutralization to below pH 9.5 suddenly transformed this system into a completely insoluble phase with a corresponding rapid reduction in viscosity. The mixture was now a dispersion of fine PF particles in an aqueous solution. To provide suitable small particle size for subsequent formulation development, the rate of acid addition and the degree of shear developed during mixing must be carefully controlled.

Advancement of the dispersion to a higher molecular weight polymer can be accomplished in a variety of ways. Thermal techniques were utilized for this project. Since this process raises PF molecular weight beyond what is commonly found in wood adhesives, conventional resin characterization methods proved unsuitable for monitoring resin advancement. One appropriate characterization technique was to redissolve the dispersion into a caustic solution using the same caustic to resin ratio present in the original plywood resin. The viscosity of these mixtures at various PF solids contents was then determined and a characteristic viscosity-solids curve constructed. Figure 1 shows a series of these curves for plywood resin A dispersions which have been heated at 160°F (70°C). Curve 1 represents a freshly precipitated resin which gives a viscosity curve similar to the original resin, indicating little change has occurred during the precipitation process. As resin advancement occurs the resin properties change to give sequentially curves 2 to 6. Curve 3 represents a condition where the mixture resembles a jelly at 10% PF solids. At this stage the polymer particles are semi-soluble but highly swellable in caustic solution. In curve 4 the particles become less soluble but are still swellable, giving the mixture a paste-like appearance. By curve 6 the mixture is distinctly two phase with most of the particles being insoluble and little swelling occurring in the caustic solution. Figure 2 gives the advancement curves for PF plywood resin B.

The next stage of formulation development was to determine which degree of resin advancement was most suitable for bonding higher moisture content veneer. Our concept was to mix this advanced resin with a conventional PF resin to produce a two phase glue mix. The advanced component would function as a reactive filler and help control glue overpenetration. This

high molecular weight component would also cure faster which would compensate for the normal cure retardation caused by the presence of moisture.

Evaluation of mixtures containing 30 to 50 % dispersion polymer component to 70 to 50 % plywood resin component established that polymer advancement of the type found in curves 3,4,and 5 of Figures 1 and 2 yields two phased glue mixtures having a wide range of viscosities. By preparing a comprehensive series of mixtures containing different proportions of dispersion and resin components at a variety of PF solids contents, information was gained on formulations suitable for glue applications. The viscosities of some of these formulations are given in Tables 3 to 5. The least advanced of these dispersion produced the highest viscosities when used in the formulation mixtures. Viscosity ranges in these Tables are divided into regions: > 10,000 cps, between 10,000 and 5000 cps, and <5,000 cps to help indicate trends. Formulation viscosities < 5,000 cps are necessary for most mill glue application purposes. These viscosity Tables indicate that a large change occurs in dispersion- resin mixtures between dispersions which have been advanced from curve 4 to curve 5 of Figure 1. It is this region of dispersion advancement which offers the greatest opportunity for a formulation mixture suitable for mill applications.

4.2 CURE STUDIES

Our previous work on PF dispersion adhesives established the advantage of utilizing incised veneer in the bonding of higher moisture content wood. Data presented in Table 6 show the large press time improvements resulting when combining incising with the dispersion-resin system. Even with non-incised veneer the dispersion formulation developed better bond quality than the standard glue mix. Incising improves permeability in the veneer allowing moisture from wet pockets to redistribute through the panel during hot pressing. Good bond quality (i.e. > 80% wood failure) is achieved within four minute press time in these 4 ply panels made with about 12% m c veneer.

Bond tests were performed in a similar manner, using formulations containing (curves 3, 4, and 5 of Figure 1) either of the three advanced dispersions described in the previous section. Panels bonded with mixtures containing the most highly advanced dispersion (curve 5 of Figure 1) exhibited relatively poor bond quality at 4 minute press times with wood failure below 50%. Increased press times did not improve this result. In these panels the appearance of the glueline indicated adhesive overpenetration with the powder portion of the mix remaining on the glueline while the liquid resin portion penetrated into the wood. This behaviour results from low viscosity of these resin -dispersion mixtures. Addition of fillers and extenders failed to improve bond quality.

Bond quality for formulations made from the other two dispersions (i.e. curves 3 and 4 of Figure 1) are presented in Tables 7 and 8. In all cases incised veneer and matched panels were used when comparing dispersion

Figure 2. Effect of Heating on Relationships between %PF Solids of Dispersion Glues and Viscosity

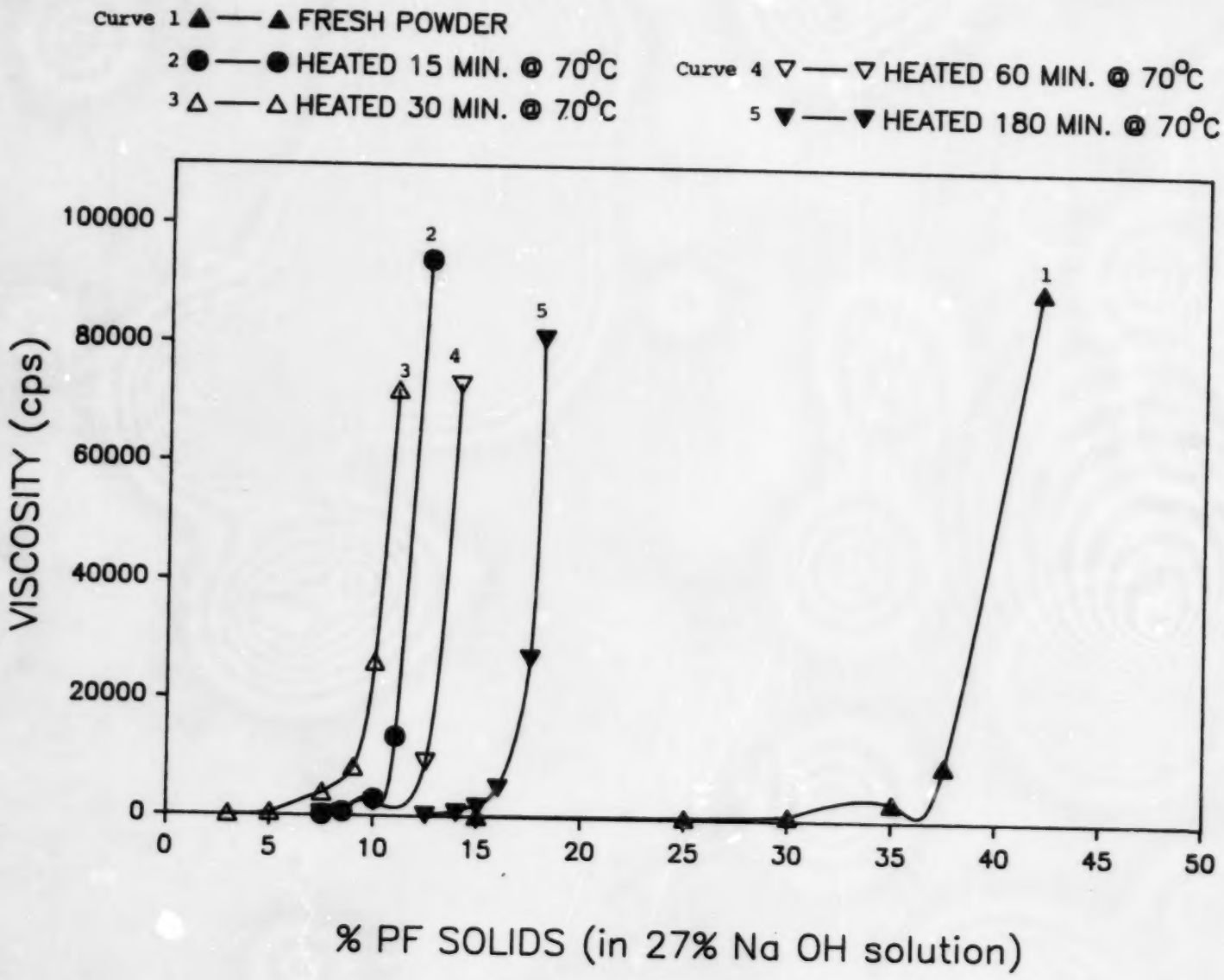

Figure 1. Relationship between % PF Solids of Dispersion Glues and Viscosity

Curve 1 ▲—▲ FRESH POWDER (PH=5.0)
2 ●—● 5 DAY OLD POWDER (PH=5.0)
3 △—△ 3 WEEK OLD POWDER (PH=5.0)
Curve 4 ▽—▽ HEATED 30 MIN. @80°C (PH=5.0)
5 ▼—▼ HEATED 30 MIN. @80°C (PH=2.0)
6 □—□ HEATED 150 MIN. @80°C (PH=2.0)

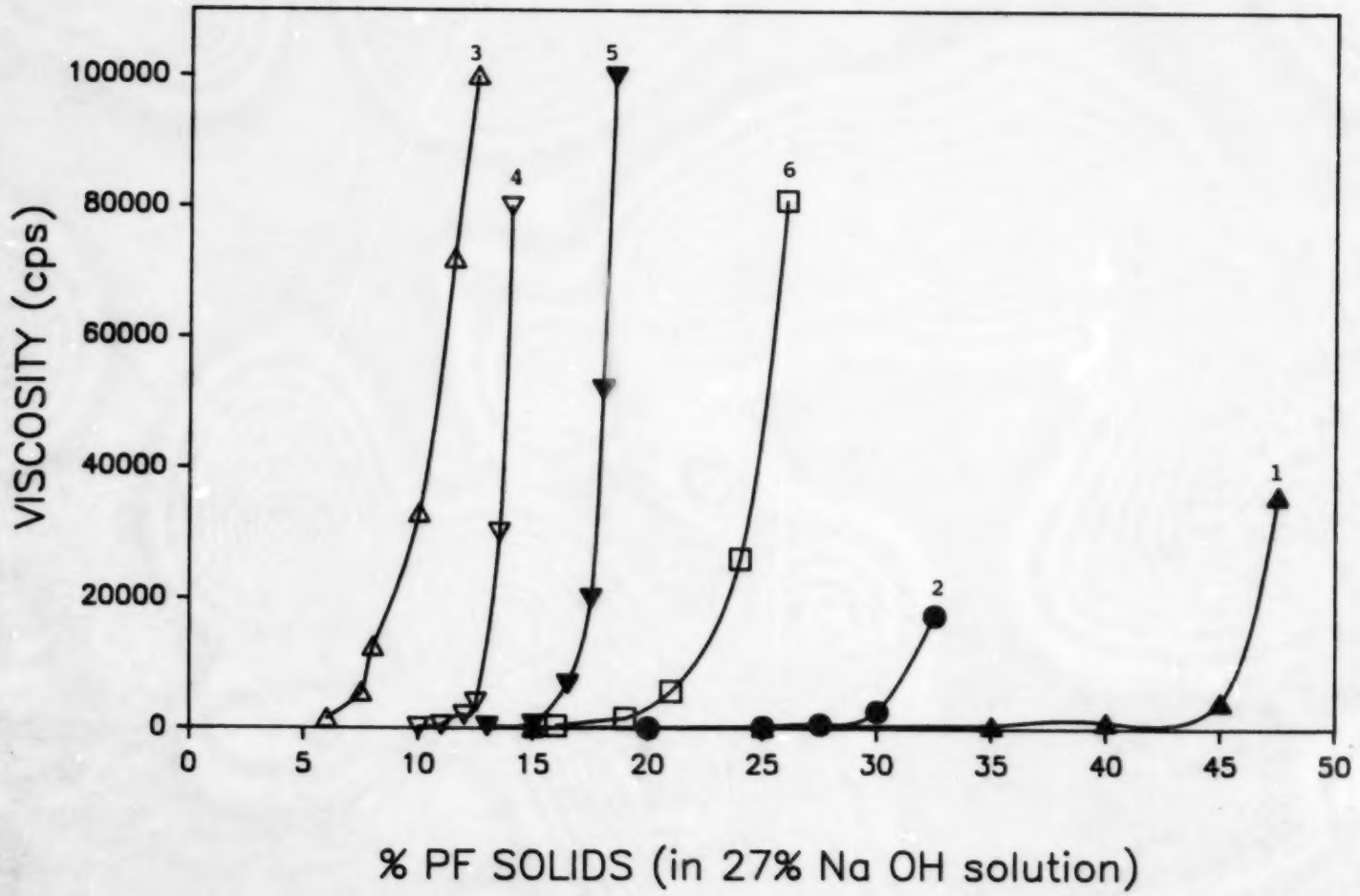

TABLE 3.

VISCOSITY OF GLUE MIX AT DIFFERENT PF DISPERSION (CURVE 3 TYPE ADVANCEMENT IN FIGURE 1) LEVELS AND PF SOLIDS CONTENT.

% PF SOLIDS	% DISPERSION IN MIX					
	36	34	32	30	28	26
35	>20000	16000	12800	11200	9200	5100
34	>20000	13900	9900	6800	5000	3500
33	19800	8700	5200	4200	2800	1700
32	9600	8400	5100	3100	2500	1600
31	7600	6000	4000	2100	1400	1000
30	6100	2000	1200	920	1000	600

TABLE 4.

VISCOSITY OF GLUE MIX AT DIFFERENT PF DISPERSION (CURVE 4 TYPE ADVANCEMENT IN FIGURE 1) LEVELS AND PF SOLIDS CONTENT.

% PF SOLIDS	% DISPERSION IN MIX					
	36	34	32	30	28	26
35	18700	13000	8900	8500	7600	3900
34	18200	15400	8900	8400	3000	2500
33	8000	5900	3600	2800	1600	1000
32	6200	4000	2500	2100	1100	700
31	1300	900	700	700	-	-
30	1000	700	500	480	300	300

TABLE 5.

VISCOSITY OF GLUE MIX AT DIFFERENT PF DISPERSION (CURVE 5 TYPE ADVANCEMENT IN FIGURE 1) LEVELS AND PF SOLIDS CONTENT.

% PF SOLIDS	% DISPERSION IN MIX							
	44	42	40	38	36	34	32	30
35	4600	4100	2800	2800	3200	2800	2600	2100
34	2800	2100	900	1600	1200	1200	800	700
33	1000	900	600	800	700	800	600	-
32	600	500	500	500	300	400	-	-
31	300	220	180	150	-	110	-	-

TABLE 6.

COMPARISON OF BOND QUALITY OF INCISED AND NON-INCISED 4-PLY, SPRUCE VENEER (12 ±2% M.C.) LAMINATES

Press-Time (min.)	Standard Glue Mix		Dispersion+ Formula #1		Dispersion* Formula #2	
	Breaking load (psi)	Wood Failure (%)	Breaking load (psi)	Wood Failure (%)	Breaking load (psi)	Wood Failure (%)
			Incised Veneer			
3		Delam	204	24	205	11
4	115	7	160	84	175	85
6	195	28	218	76	210	95
8	247	40	227	78	253	92
10	249	94	255	92	235	97
			Non-Incised			
3		Delam	165	25	165	40
4	50	3	176	24	246	24
6	152	2	281	30	283	28
8	227	7	267	52	284	30
10	197	67	152	82	226	70

Note: Each value is an average of ten samples

+ Dispersion system similar to those used in the present study

* Dispersion system containing phenol-resorcinol-formaldehyde resin

TABLE 7.

Bond Quality of Laboratory Pressed Panels with 10-12% M.C. Veneer; dispersion powder characteristic of Curve #3 of Figure 1. 4 min. Press Time; 1/2" Panel

Solids (%)	Dispersion Powder (%)	Control		Dispersion	
		Breaking load (psi)	Wood Failure (%)	Breaking load (psi)	Wood Failure (%)
35	27	98	18	160	78
	26	193	31	176	89
	25	148	53	154	90
34	30	141	54	165	96
	28	193	31	198	95
	26	148	53	157	85
33	34	160	62	212	96
	32	208	31	227	69
	30	158	46	177	87
	28	208	31	213	71
	26	158	46	215	88
32	36	141	54	157	95
	34	161	36	177	91
	32	172	47	186	66
	30	161	36	147	74
	28	172	47	197	84
31	40	169	39	175	88
	38	170	33	218	51
	36	169	39	181	83
	34	170	33	184	59
	32	188	12	261	45
	30	192	7	219	24

Note: Each value is an average of ten specimens

TABLE 8.

Bond Quality of Laboratory Pressed Panels with 10-12% M.C. Veneer; dispersion powder characteristic of Curve #4 of Figure 1. 4 min. Press Time; 1/2" Panel

Solids (%)	Dispersion Powder (%)	Control		Dispersion	
		Breaking load (psi)	Wood Failure (%)	Breaking load (psi)	Wood Failure (%)
35	32	155	58	149	94
	28	147	40	183	95
	24	179	39	187	78
34	44	153	24	145	53
	40	152	24	157	39
	38	156	58	154	86
	34	120	28	179	67
	30	147	40	155	98
	24	123	12	159	59
33	36	123	12	141	45
	30	117	20	165	99
	26	117	20	199	70
32	38	120	28	169	57
	30	138	6	229	43

Note: Each value is an average of ten specimens

formulations to a standard PF control glue mix. The general data trend indicated that as PF resin solids decrease, the bond quality declines. The amount of dispersion component in the formulation also had an effect on bond quality. For instance, in Table 8 at 34% solids, poorer bond quality resulted when dispersion content was above 38% while in Table 7 at 31% solids, bond quality declined as dispersion level fell below 36%. Bond quality of control samples were also poor in these cases also suggesting the possibility that lower bond quality results may be a consequence of overall poor veneer quality. Another factor influencing bonding was the high viscosities of mixtures containing large amounts of dispersion and the low viscosities of those with low dispersion content. Both situations affected application and transfer of glue. Nevertheless in all cases described here the dispersion resin formulation performed better than the standard, control glue mix.

It was concluded from these resin development and cure studies that :

- a dispersion-resin system can be produced which is capable of bonding veneer at about 10% m c.
- the formulation can be filler and extender free.
- for application and bonding purposes the dispersion must be advanced so that PF particles are insoluble but swellable when mixed with an alkaline, liquid PF resin. The acceptable degree of swelling will depend upon application method and veneer properties.
- acceptable adhesives can be achieved with formulations in the range of 32 to 35 % solids and containing 28 to 38% dispersion components.

4.3 APPLICATION OPTION

Glues were applied by roller method during the laboratory phase of formulation development. This method accommodated variations in dispersion particle size and glue mix viscosities. Since most candidate mills for glue trials operated with spray systems, close attention was given to glue working properties in order to insure spraying could be accomplished. Dispersion particle sizes < 40 mesh and mix viscosities of 1500 to 3000 cps were targeted. Discussions were held with Borden Chemicals on mix characteristics required for spraying and the potential for scaling up our resin system to mill trial volumes.

Detailed attention was given to veneer m c range required for mill trials. It was recognized that current mill drying operations produce non-uniform m c veneers. Variations can be found within a sheet (i.e. wet pockets) and between veneers. In mills attempting to use higher m c levels , dryer speeds are increased and a good portion of redry sheets are stacked and given 24 hrs to equilibrate. During this period some moisture migration occurs but wet pockets still exist. To insure better moisture uniformity

during our tests, veneers were either air dried or kiln dried under mild conditions. Moisture uniformity was confirmed by sampling several sections in a number of sheets.

4.4 INITIAL SCALE-UP

Scale up procedures involved increasing glue mix size from 22 lbs to 440 lbs (10 kg to 200 kg). The three crucial process stages: precipitation, polymer advancement and mixing of dispersion and resin components were accomplished with the aid of a high shear stirrer in combination with a circulating pump. Combining high shear mixing with slow acid addition was essential for attaining small PF particle size during precipitation. Difficulties were sometime encountered when heating large quantities of the dispersion to advance the polymer. In particular, particle agglomeration occurred when temperatures exceeded 165°F (75°C), which frequently happened near the heating elements when agitation was inadequate. Good particle distribution in the final glue mix was best achieved by adding the dispersion to the liquid resin under high shear mixing.

4.5 SMALL MILL TRIALS

Three small mill trials were undertaken at Cantree Plywood in New Westminster B.C. The purpose was to test the spray system and the bonding potential of our moisture tolerant adhesive system on commercial plywood manufacturing equipment. These trials utilized only one or two spray booths in order to limit glue mix quantities to about 440 lbs (200 kg).

4.5.1 First Mill Trial (May 1988)

This trial was designed to assess the spray characteristics of our glue mix. The test mix consisted of 35% PF solids and contained 35% dispersion component. Mix viscosity was about 9500 cps and some particle agglomeration was evident. Difficulties were encountered in pumping this mixture to the spray head. Increasing pump pressure partially alleviated this problem but the spray pattern was poor. The pattern consisted of large drop sizes, a small fan pattern less than four feet in width and intermittent plugging of the nozzle by large resin particles. It was concluded that for proper spraying: glue viscosity must be reduced, large particles must be eliminated from the glue mix and a pump with a larger pressure adjustment range was needed.

To help sort out these spray problems a pilot-plant-size-spray line was constructed in our laboratory. The system included a variable speed conveyor, a large capacity pump and a spray booth with a commercial spray tip nozzle. A number of tests were conducted on this system to determine the best sprayable glue formulations before proceeding to the next trial.

4.5.2 Second Mill Trial (July 1988)

For this trial, commercially peeled spruce veneer was incised and air dried in our laboratory. These veneers were monitored with a moisture meter until average m c of 12% was reached (moisture pockets in these veneers ranged from 9 to 16%). The mix formulation of 33% PF solids and 33% dispersion component gave a viscosity of 4000 cps which produced a good spray pattern in the mill. Prior to transfer to the mill, the mixture was evaluated for bonding capabilities in our laboratory. These results are shown in Table 9, trial #2, which indicate good bond performance. Exclusion of filler in these mixes allowed finer spray droplets to form, giving improved veneer coverage in comparison to a standard glue mix. Mill assembly times which ranged up to 15 to 40 minutes, were longer than desired since the trial was limited to one spray booth. This may have adversely influenced bond quality.

Prepress properties of the dispersion mix were excellent while the Borden's mix performed poorly at these veneer moisture contents.

Steam blisters could be seen in most panels when the press opened at the end of its schedule. Examination of the panels revealed that many of the Borden glued panels were completely delaminated while the dispersion glue mix panels held together,although poor bond quality was evident upon knifing open the glueline.

One Reason for poor bond results became evident after determinations were made of panel moisture content out of the press. Ovendry measurements of three panels found m c ranging from 16.6 to 18.5%, substantially more than expected. Similar tests of veneer showed average sheet m c ranging between 14 and 17 %, a finding which indicated the inaccuracy of using a ring type moisture meter to determine m c. Although veneer m c was much higher than targeted, the fact that the dispersion adhesive both prepressed and bonded better than the commercial moisture tolerant glue indicated the potential of this glue system. The ovendry method was used to determine veneer moisture content in the remaining studies.

4.5.3 Third Mill Trial (Sept 1988)

For this trial green commercial veneer was incised and mildly dried in a lumber kiln until an average m c of 9%. Prior to the trial, the dispersion glue mix was tested for bonding properties. Data presented in Table 9, trial 3 indicates the good bonding achieved with this system. Two spray booths were used to facilitate faster panel assembly. The dispersion mix again yielded an excellent spray pattern, although occasional layup line problems resulted in overspray in a few panels. All panels prepressed well. On press opening several small steam blisters were observed in the dispersion mix panels while more frequent and larger blisters were detected in the control glue mix panels. Passing these panels through a blister detector confirmed these initial observations. Visual examination of bond quality by knifing open the glueline revealed better wood failure in the dispersion mix panels than in control glue mix panels , although both sets failed to meet the bond quality requirements

TABLE 9.

Summary of Bond Quality for 4 Ply-Laminated Strips bonded with Dispersion Adhesives Prepared for Mill Trials.+

Trial	Press time (min)	DISPERSION MIX		CONTROL* MIX	
		Breaking load (psi)	Wood Failure(%)	Breaking load (psi)	Wood Failure(%)
#2	4	119.9	88.1	104.4	36.6
	5	195.0	86.9	191.7	60.0
#3	4	184.0	87.5	174.0	71.0
	5	159.0	99.1	205.0	94.5
	6	165.0	90.4	171.0	75.0
Zeidler	3	170.0	79.5	135.0	12.9
	4	190.0	98.3	176.0	36.7
	5	191.0	73.3	138.0	31.8

\+ Using spruce veneers at 11±2% m.c.; press conditions of 185 psi (1.3 MPa) pressure and 300°F (150°C). Specimens were tested after vacuum-pressure soak treatment.

* Borden's moisture tolerant 2020 glue mix.

Note: Each value is an average of ten specimens

of the Canadian Plywood Standard. Dryout was found in some gluelines of panels with longer assembly times (i.e. 25 min).

Observations during press opening suggested that rapid pressure release does not give sufficient time for moisture to re-equilibrate in the panel. Significantly reducing pressure just before press opening would allow improved moisture redistribution with reduced blister formation.

This trial demonstrated that a sprayable, filler free, dispersion mix system can be used on an automatic layup line to bond panels at higher m c levels. Reduction in average veneer m c from 9 to 10% range to about an 8% level would likely reduce blisters.

4.5.6 Refinement and Final Scale-up

Further tests were undertaken on our laboratory sprayline to help refine the final formulation makeup. Some of these tests involved the use of a larger orifice spray nozzle, similar to equipment installed in Zeidler's mill. Based on the small mill trials and these sprayline tests, a formulation comprising 35% PF solids with 33% dispersion component, having a viscosity between 1800 and 3000 cps was targeted for our final trial. Laboratory board test of the target formulation were undertaken and bond quality is reported in Table 9, Zeidler trial.

Several barrels of a plywood resin were obtained from Borden Chemicals and used to prepare the trial resin.

Green veneer was shipped from Zeidler's mills to Forintek where it was incised and carefully dried. No attempt was made to segregate species into different loads. Some surface discoloration was noted after drying, especially in the pine veneers. Since sheets in each pile were stickered during drying, wood movement to accommodate shrinking and swelling stresses was restricted resulting in large splits appearing in many sheets, especially those containing compression or tension wood. Consequently great care was required in handling these veneers during restacking.

4.6 ZEIDLER MILL TRIAL

4.6.1 Glue mix

Borden's plant in Edmonton supplied the 500 gallon (1890 liters) mixing facility to prepare the dispersion-resin formulation. Proper mixing was hindered by the fact that the dispersion component settled during transportation from Vancouver and the stirrer had limited shear action. Final mixture appearance was that of a liquid resin with light coloured particles distributed throughout. Some particles were larger than desired, presumably because of the settling of the dispersion and the limited mixing capabilities in the tank. Filtering equipment was not available at the plant to remove these large particles.

Since the mill trial at Zeidler, the above problems including the filtering were overcome, and Borden has successfully participated in preparing two large batches (ton quantities) of dispersion glue suitable for mill trials. These batches of dispersion glue were tested under mill conditions and found to give excellent spray and tack properties. As well, bond quality was evaluated according to the CSA-0151-M1978 standard, and the average percent wood failure for the vacuum-pressure test surpassed the 80% requirement of the standard.

In further cooperation with the Zeidler mill, since the mill trial at Zeidler, we have supplied Zeidler with a veneer incisor for them to assess the effects of incising their veneer with regards to drying and bonding.

4.6.2 Plywood mill trial (Nov. 8,1988)

The glue mix viscosity increased to about 3000 cps, after standing overnight, but was still sprayable. A total of 15 press loads were assembled, each containing various combinations of veneer and glue. These combinations and the pressing conditions used are summarized in Tables 1 and 2.

Some panels were observed to blister during the first two press loads. Consequently all press loads following load 3 were pressed at 285°F (140°C)' which is the normal mill operating temperature, rather than 300°F (150°C)'

The following observations were made during the trial:

- the dispersion formulation sprayed well and allowed for easy layup operation
- larger particles present in the glue mix caused occasional clogging of spray tips and parts of the filtering system. Improved high shear mixing and prefiltering would solve these problems.
- kiln dried, incised veneer was difficult to handle in the automated layup system because of the splits and breaks created during drying and handling. Several line stoppages were needed to clear mangled sheets.
- mill personnel were concerned about the darker colour of some of the kiln dried pine veneer. This may have indicated surface inactivation which would hinder bonding.
- prepress behaviour of the dispersion system was as good or better than with Borden's glue.
- on press opening some blisters could be seen from all press loads, even the ones having panels made from standard mill veneer and

Borden's glue.

- knifing the panel behind the press showed limited glueline wood failure for some of the panels made with incised veneer and dispersion glue but good wood failure was found in panels made from standard mill veneer and dispersion glue.

To complete our data collection samples of dried mill veneer were selected from sapwood, heartwood and random piles for moisture content determinations. In addition two panels each from press loads 4 and 11 were taken and strips cut out to determine panel moisture content. These moisture determinations are reported in Table 10. The average m c in the standard mill veneer is about 3.0% for heartwood and 6.2% for sapwood while the incised veneer was 7.6% overall. These differences are also reflected in panel average m c where those made with incised veneer and dispersion glue averaged 8.2% m c almost 3 % higher moisture than the standard panels made in Zeidler's plant.

4.7 PANEL ASSESSMENT

Visual inspection of panels indicated edge delamination was present in at least one panel from each layup type. Panels made from incised veneer and Borden's glue showed the greatest amount of edge delamination with six out of seven sample panels being affected.

A summary of delamination areas detected in panels scanned through a blister detector are presented in Table 11. Panels made with Forintek's dispersion adhesive and either mill veneer or a mixture of incised and mill veneer yielded the highest number of blister free panels. The next best blister free panel type were those made with incised veneer and dispersion glue. Panels with the greatest number of blisters were from standard mill panels and incised veneer panels with Borden's glue. In terms of blister formation the dispersion glue mix appears to perform better than Borden's moisture tolerant glue in bonding of incised and regular mill veneer.

Shear strength and wood failure data of plywood specimens cut from randomly selected panels provide a further indication of bond quality. This data is summarized in Tables 12 to 17.

With the limited number of panels pressed and sampled, it was not surprising that variations in bond quality were found between panels in the same press load and within the same layup type. The combination of veneer variability, and mixtures of different species in each panel, possible overdrying of the incised veneers and difficulties encountered during mixing of the dispersion adhesive likely were factors in panel variability. Considering average wood failure values for each panel type (Table 17), most of the data falls within a similar range except for the panels manufactured from a mixture of mill and incised veneer which were bonded with dispersion adhesive (type D). These yielded superior wood failure values. Here, mill veneers were used as crossbands, while

TABLE 10.

AVERAGE M.C. OF DRIED VENEER AND PANELS

	AVERAGE MC (%)
Zeidler mill veneer samples:	
Heartwood	3.0
Sapwood	6.2
Random Mixtures	2.3
Incised veneer dried at Forintek	7.6
Panels made with incised veneer and dispersion glue	8.2
Panels made with mill veneer and Borden's 2020 moisture tolerant glue	5.3

TABLE 11.

SUMMARY OF BLISTER DATA FROM ZEIDLER MILL TRIAL PANEL[+]

PANEL TYPE	DESCRIPTION[@]	NO. OF PANELS[*]	BLISTERS DETECTED			% NONBLISTERED PANELS
			ZERO	SINGLE	MULTIPLE	
A	Mill Veneer Borden Glue (Standard Zeidler Panel)	10	2	0	8	20
B	Incised Veneer Borden Glue	7	1	0	6	14
C	Mill Veneer Forintek Glue	20	13	1	6	65
D	Mixed Mill & Incised Veneer Forintek Glue	9	5	1	3	56
E	Incised Veneer Forintek Glue	21	8	2	11	38

[+] Blister detector set at normal mill setting of 7.

[*] Panels mismanufactured (i.e. severe glue overspray, veneer overlap or multi-veneer gaps) not counted.

[@] Mill veneer = Zeidler's standard veneer at m.c. from 3 to 6%
Incised veneer = Zeidler's veneer, incised and dried at Forintek to 7.6% average m.c.

TABLE 12.

BOND QUALITY FOR PANELS MADE FROM STANDARD MILL VENEER AND BORDEN'S 2020 GLUE.

PANEL	VACUUM PRESSURE		BOIL-DRY-BOIL	
	Breaking load (psi)	WOOD FAILURE (%)	Breaking load (psi)	WOOD FAILURE (%)
11-3	134.3	68.6	173.9	72.8
11-5	177.3	89.0	162.5	78.1
12-2	171.3	40.0	172.2	65.0
12-3	171.0	60.5	138.8	56.3
12-4	143.5	73.3	123.6	66.4
AVERAGE	159.5	66.3	154.2	67.7

* Average values according to CSA 0151 1978

TABLE 13.

BOND QUALITY FOR PANELS MADE FROM INCISED VENEER AND BORDEN'S 2020 GLUE.

PANEL	VACUUM PRESSURE		BOIL-DRY-BOIL	
	Breaking load (psi)	WOOD FAILURE (%)	Breaking load (psi)	WOOD FAILURE (%)
9-2	113.9	74.4	108.1	89.4
9-4	252.0	59.5	218.3	42.8
10-1	115.0	85.5	101.9	90.6
10-4	167.2	77.8	147.2	81.7
10-5	222.8	33.3	230.0	60.6
AVERAGE	174.2	66.1	161.1	73.0

* Average values according to CSA 0151 1978

TABLE 14.

BOND QUALITY FOR PANELS MADE FROM STANDARD MILL VENEER AND FORINTEK DISPERSION GLUE.

PANEL	VACUUM PRESSURE		BOIL-DRY-BOIL	
	Breaking load (psi)	WOOD FAILURE (%)	Breaking load (psi)	WOOD FAILURE (%)
1-4	202.5	84	138.3	88.9
1-5	133.3	94.5	127.0	90.0
13-2	177.0	49.5	192.8	35.0
13-3	154.5	84.0	87.5	81.3
13-5	118.0	75.0	107.2	75.0
14-1	97.8	63.9	109.5	55.0
14-2	107.5	51.0	101.6	52.2
14-3	132.1	82.5	133.8	84.4
15-3	110.0	49.4	103.8	53.1
15-5	146.7	40.0	110.5	31.0
AVERAGE	137.9	67.5	121.2	64.6

* Average values according to CSA 0151 1978

TABLE 15.

BOND QUALITY FOR PANELS MADE FROM MIXED MILL AND INCISED VENEER AND FORINTEK DISPERSION GLUE.

PANEL	VACUUM PRESSURE		BOIL-DRY-BOIL	
	Breaking load (psi)	WOOD FAILURE (%)	Breaking load (psi)	WOOD FAILURE (%)
2-3	149.4	92.5	138.0	85.0
2-4	165.5	89.0	97.5	100.0
3-1	163.3	99.4	143.5	99.5
AVERAGE	159.4	93.6	123.3	94.8

* Average values according to CSA 0151 1978

TABLE 16.

BOND QUALITY FOR PANELS MADE FROM INCISED VENEER AND FORINTEK DISPERSION GLUE.

PANEL	VACUUM PRESSURE		BOIL-DRY-BOIL	
	Breaking load (psi)	WOOD FAILURE (%)	Breaking load (psi)	WOOD FAILURE (%)
4-3	133.3	91.7	144.4	96.1
4-5	116.0	64.5	94.5	86.3
5-1	145.0	87.8	99.0	78.5
5-5	135.7	68.6	130.0	53.8
6-1	112.0	90.0	102.2	73.6
6-4	117.7	78.9	109.0	71.5
7-1	149.0	59.0	141.0	21.2
7-5	146.7	58.9	142.2	51.2
8-3	119.4	67.2	150.6	39.4
AVERAGE	130.6	74.1	123.6	63.4

* Average values according to CSA 0151 1978

TABLE 17.

SUMMARY OF AVERAGE BOND QUALITY FOR DIFFERENT PANEL TYPES

PANEL TYPE	DESCRIPTION	VACUUM PRESSURE		BOIL-DRY-BOIL	
		Breaking load (psi)	WOOD FAILURE (%)	Breaking load (psi)	WOOD FAILURE (%)
A	Mill veneer and Borden's glue	159.5	66.3	154.2	67.7
B	Incised veneer and Borden's glue	174.2	66.1	161.1	73.0
C	Mill veneer and dispersion glue	137.9	67.5	121.2	64.6
D	Mixed mill and incised veneer and dispersion glue	159.4	93.6	123.3	94.8
E	Incised veneer and dispersion glue	130.6	74.1	123.6	63.4

* Average values of all specimens of each panel type tested according to CSA 0151 1978

incised, full sheets were used as face, back or core veneers.

Although some panel types from each layup type had wood failure values which pass CSA standards, the average of each set did not attain the required 80% wood failure except for those panels in Table 15.

Bond performance comparisons in Type A and C panels (Table 17), both of which used mill veneer but different adhesives, showed the dispersion adhesive to perform as well as the Borden's moisture tolerant glue. However, in terms of the number of blister free panels (Table 11) the dispersion adhesive type C panels were superior to the control panel type A.

Incised veneer bonded with either Borden's or dispersion adhesive (types B and E) gave similar bond quality although type E had lower average strength but a greater proportion of blister free panels. It should be remembered that the average moisture level of incised veneer was over 3% greater than standard mill veneer.

The superior bond performance of panels containing mixtures of incised and mill veneer is likely due to a number of factors. These include: the lower average m c of this panel compared to one containing all incised veneer, the presence of some incised veneers which would improve vapour permeability and the use of a filler free, dispersion glue formulation.

5.0 CONCLUSIONS

Development of a two phased PF glue formulation and its use in plywood mill trials has demonstrated the viability of the dispersion adhesive system for bonding higher moisture content veneer.

An added benefit is that this formulation requires no filler. This adhesive system has the advantage that design modifications can be readily made to accommodate a range of wood moisture contents and species. Either roller or spray techniques can be utilized to apply the adhesive. These mill trials have further demonstrated the benefits arising from a plywood bonding program which includes moisture sorting of veneer, incising, and the use of moisture tolerant adhesives.

6.0 COMMERCIAL SIGNIFICANCE

Dispersion glues offer a unique approach to utilizing filler free PF adhesives to bond plywood. Zeidler personnel are interested in continuing this testing program not only from consideration of higher m c bonding capabilities but also from the potential cost and application advantages of having a filler free formulation. Borden's, through an agreement signed

with Forintek is interested in co-operating in the further development of this system to eventual commercial applications.

7.0 RECOMMENDATIONS

To gain the full advantage of these dispersion glues further development is needed. This should include studies of dispersion glue mixing procedures and pot life of these systems. It is recommended that further small mill trials be undertaken in which the dispersion glue is directly substituted into plants already using commercial moisture tolerant adhesives. This would demonstrate the bonding capabilities of this formulation under present veneer moisture sorting conditions (about 4.5 % average m.c.). There should then be a systematic increase in veneer m c by dryer speed adjustment to about 8% average m c over several stages to allow bond development assessment and formulation refinement to take place. In this manner the proper matching of veneer moisture level with adhesive bonding capabilities can occur.

8.0 REFERENCE

CSA 0151-1978 Canadian Softwood Plywood Standard. Canadian Standards Association, Rexdale, Ontario.